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GEOTHERMAL EXPLORATION AND DEVELOPMENT IN ETHIOPIA: A COUNTRY UPDATE

Mesay Fekadu Biru
Ethiopian Electric Power
Addis Ababa
ETHIOPIA
abushmech@gmail.com

ABSTRACT

Ethiopia is endowed with large geothermal resources with estimated geothermal electrical potential of over 10,000 MW. These resources are located in the Ethiopian Rift valley, which is part of the East African Rift system. The policy of the government is to generate electricity as much as possible from clean and renewable sources centered on hydropower, geothermal, wind, solar and other renewable energy resources, using public and private sector investments. The current total installed electricity generation has reached over 5000 MW. To date, the number of prospects identified to have high-temperature resources has reached 25, out of which 20 have been explored with detailed surface exploration, and in three areas, deep drillings have been conducted. The only power plant installed in the country so far is a 7.3 MW binary plant at Aluto Langano Geothermal field. Currently, deep geothermal drilling activities are being carried out at Aluto Langano and Tulu Moye prospects by the public and the private sector, respectively. A well-head turbine is also being installed at Aluto Langano prospect. A total of 980 MW of electricity is planned to be developed from geothermal by 2030 from six committed projects and six candidate projects with public and private sector funds.

1. INTRODUCTION

1.1 Country background

Ethiopia is located in the horn of Africa between 3.5° and 14° N and 33° and 48° E. The country has an area of 1.14 million km^2 and a population of over 100 million (CSE, 2016). The Ethiopian economy is a non-oil-driven economy, which is agricultural-led, with major exports of coffee, oil seeds, animal skin and horticultural products. The government set-up has been a federal democratic republic with eleven regional states.

1.2 Energy and electricity sector

1.2.1 Sources of energy and status of electricity production

The sources of energy in Ethiopia can be generally categorized into two major components: (i) traditional (biomass); and (ii) modern (such as electricity and petroleum). Of the total energy consumption, 87% is from traditional and derived biomass, 10% is from petroleum products and coal, and only 2% is from electricity (Eshetu, 2019).

The total installed electrical capacity has reached over 5000 MW. From these, 4827 MW is from hydro, 7.3 MW is from geothermal, 349 MW is from other renewable sources and 89 MW is from fossil fuels (Table 1).

TABLE 1: Sources of current generation in Ethiopia and corresponding installed capacity

No	Source of generation	Installed capacity (MW)	%
1	Hydropower	4,827	91.6
2	Other renewables	349	6.6
3	Geothermal	7.3	0.13
4	Thermal	89	1.7
	Total	**5,272.3**	100

*Other renewable energy resources include wind, solar and waste to energy

1.2.2 Energy policy and regulation

The government policy direction is to generate virtually all of Ethiopia's electricity from clean and renewable sources centered on hydropower, geothermal, wind, solar and other renewable energy resources (Eshetu, 2019). It aims to facilitate the development of energy resources for economical supply to consumers. It seeks to achieve the accelerated development of indigenous energy resources and the promotion of private investment in the production and supply of energy. Electricity supply, as an element of the development infrastructure is being advanced by the government on two fronts: (i) the building up of the grid-based supply system to reach all administrative and market towns; and (ii) rural electrification based on independent, privately owned supply systems in areas where the grid has not reached.

An independent power producer (IPP) may engage in power development for selling the generated electricity to the public utility, Ethiopian Electric Utility (EEU), known as the single buyer model. The single buyer model does not exclude captive geothermal power generation, i.e. generation for own use in primary economic production or service industries owned by the developer. Recently, policies on public-private partnerships (PPP) options are also put into force.

A new geothermal law for the operation of geothermal activities for both the public and private sectors has been approved. The proclamation cited as the "Geothermal Resources Development Proclamation", has been put in to force since 2016. The objectives of this proclamation are to: (i) ensure that the country's geothermal resources are developed in an orderly, sustainable and environmentally responsible manner; (ii) support the generation and delivery of electricity from geothermal energy for local consumption and export; and (iii) promote the use of low enthalpy geothermal resources for direct uses (Federal Negarit Gazette, 2016).

1.3 Institutional set-up in geothermal

The surface exploration work to date has been carried out by the Geological Survey of Ethiopia (GSE). Ethiopian Electric Power (EEP) is currently engaged in deep drilling and power plant development. The EEU is responsible for electric power distribution and the purchase and sale of electric power. A geothermal licensing and administration department which has recently moved from the Ministry of Water and Energy to the Ministry of Mines has a mandate of handling geothermal regulatory issues.

2. Geothermal exploration and development in Ethiopia

2.1 Geology background

The East African Rift system cuts Ethiopia from northeast to southwest forming a topographic depression known as the Ethiopian Rift system (ERS) (Figure 1). The Ethiopian Rift system is divided into: the Main Ethiopian Rift (MER) and the Afar depression. The MER extends in a NNE-SSW trend and is dominated by occurrences of silicic volcanoes with underlying remnant magmas as heat sources. On the other hand, volcanism in the Afar depression has been related, mainly to NW-SE trending fissured structural systems with some eruptive centers. The composition of the lavas produced in Afar ranges from basalt dominated to siliceous types. The lower elevations of the Rift floor are mainly filled with young sediments of Quaternary age.

2.2 Geothermal exploration and development in the past

2.2.1 Surface exploration by the public sector

Ethiopia is endowed with large geothermal potential. The geothermal resources are located in the Ethiopian Rift valley, which is part of the East African Rift system. The geothermal sites in Ethiopia are geographically distributed from the southwestern part of the Ethiopian Rift up to the northeastern part (Figure 1).

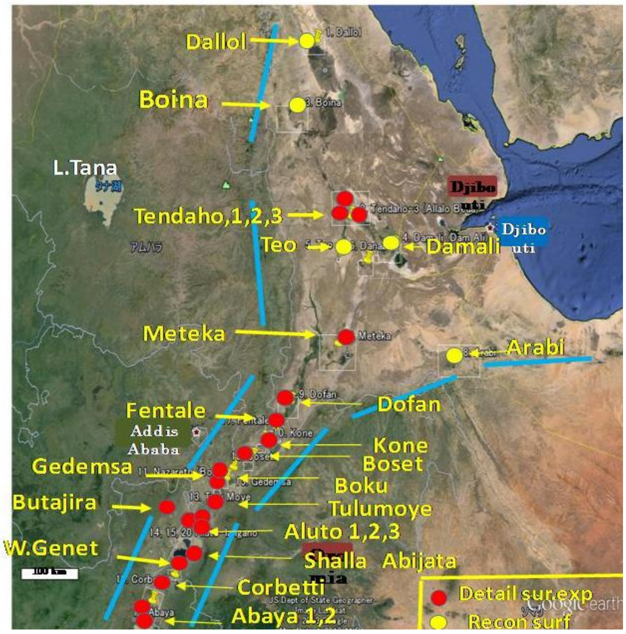

FIGURE 1: ERS and location map of geothermal prospects in Ethiopia

Ethiopia started geothermal exploration in 1969, within the Ethiopian sector of the East African Rift system. To date the number of prospects identified to have high-temperature resources has reached 25. The initial level of exploration was reconnaissance, which included regional infrared air-borne surveys covering the whole rift system (UNDP, 1973).

Since the late 1970s, geoscientific surveys, mostly comprising geology, geochemistry and geophysics, were carried out at the southern-central part of the Ethiopian Rift and Tendaho prospect in Afar to the north. In addition, a semi-detailed surface exploration of ten sites in the central and southern Afar was carried out in the mid-1980s (ELC, 1986). So far, studies have completed detailed surface explorations in 20 of the 25 prospects (Figure 1).

Aluto Langano prospect

One of the best-explored areas is the Aluto Langano prospect. More detailed surface exploration of the prospect was carried out in 2015-2016, focusing on the main anomaly areas, Aluto 1, 2 and 3 (Figure 2), with the objective of identifying the most favorable sectors within the Aluto volcanic complex for the implementation of further underground exploration activities.

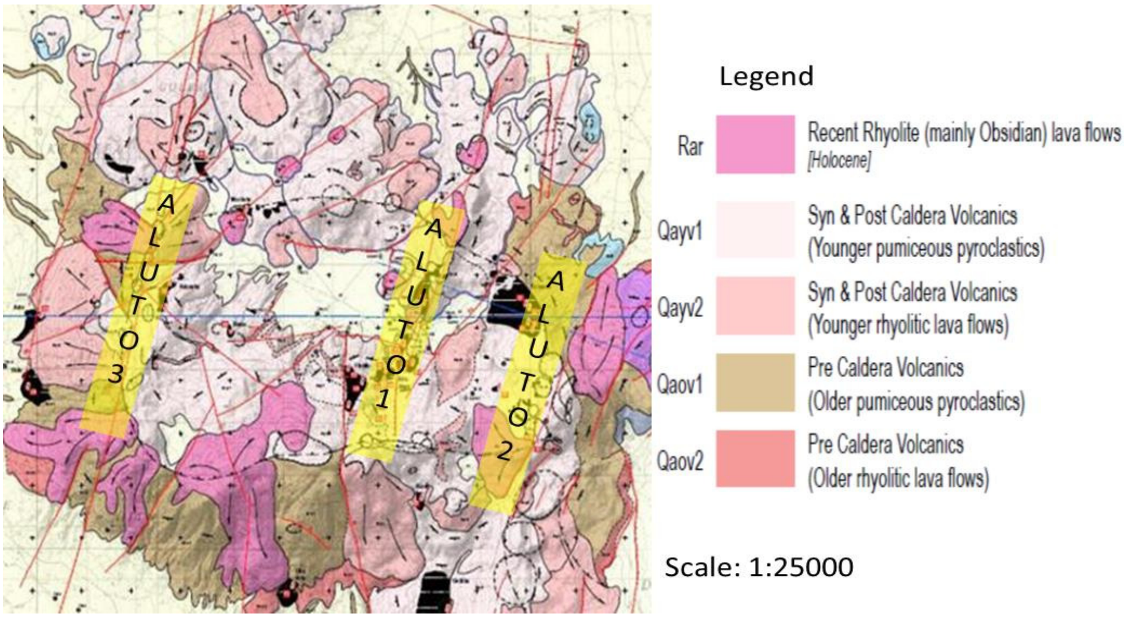

FIGURE 2: Geologic map of Aluto volcano (modified from ELC, 2016a)

To achieve the objectives of further underground explorations, geological, geochemical and geophysical surveys (gravity, geoelectrical and micro-seismic) have been conducted. The integrated interpretation of the results of these surveys led to the following conclusions: (i) the geovolcanic situation may create an intense, wide and shallow thermal anomaly; (ii) the main element controlling the configuration of the geothermal system is represented by NNE-NNW trending faults; (iii) the other structural elements of major importance are elongated in a W-E direction over an extension of 8.5 x 5 km; (iv) from resistivity survey clay caps corresponding to top of the reservoir have been identified in the central (Aluto 1) and eastern portion of the volcano (Aluto 2) (Figure 2) and these two areas have been selected as future targets for drilling; (v) the two areas are expected to have a power output of at least 70 MW; and (vi) the reservoir fluids are of Na-HCO_3-Cl type with average total salinity of 100 meq/kg and non-condensable gas content of 6-8% in the steam, with low scaling and corrosion potential (ELC, 2016a).

Tendaho geothermal prospect

The Tendaho prospect involves three target areas, named Tendaho 1, 2 and 3 (Figure 1). Surface exploration in the target area of Tendaho 1 was finalized under the framework of the ARGeo project in 2013. The purpose of the survey has been to develop a conceptual model and select deep well sites. A review of all the available geoscientific data of the Tendaho area, the development of a new 3D model of subsurface temperature and the definition of areas of interest for further exploration and development have been made. The new developed conceptual model is largely consistent with previous assessments. Initial exploration wells have been sited to be drilled to validate the model.

At Tendaho 2, detailed surface exploration, including geophysical (MT/TEM, gravity and micro-seismic) and environmental studies have been conducted in 2015 for siting of wells. The results have indicated priority areas for test well drilling. Accordingly, the drilling of 2 to 3 wells has been planned for the near future.

Surface exploration at Tendaho 3 was completed in 2015, with technical assistance from Iceland. The exploration works included geophysical exploration (MT, gravity and micro-seismic) and subordinate other geoscientific methods. The purpose of the exploration was to have a conceptual model of the geothermal system for subsequent well-site selections. The developed conceptual models of the field have indicated that there may be three target areas in order of priority and a total potential of about 125 MWe.

According to the conceptual model of Tendaho 3, the main features of the hypothesized reservoir, with reference to the first priority zone, have been estimated as follows: (i) in areal extent covers a surface of 8 km^2, being delimited at all sides by geo-electrical lateral discontinuities; (ii) in vertical extent the top of the reservoir occurs at an average depth of about 1,000 m b.g.l. and the thickness is assumed to be in the order of 1,000-1,200 m; and (iii) the reservoir is expected to be liquid dominated with a temperature of 200-220°C, fluids have a Na-Cl composition with relatively high content of SO_4, and are rather diluted (TDS around 1,400 ppm) and may exhibit some calcite and silica scaling tendency (ELC, 2016b).

Surface exploration in other areas
Surface exploration was conducted in Shalla-Abiata and Butajira areas, in the central part of the Rift in 2016. Geological, geochemical and geophysical surveys including MT have been conducted by GSE. The preliminary results of the survey in these two prospects indicated that geothermal reservoirs with temperatures in excess of 200°C might likely exist at depth. Similar geoscientific data has also been collected at Meteka in 2017/18, which has been used to conceptually model the geothermal system and indicated preferred areas for further investigation (ELC, 2019). In 2021 additional surveys in MT and geochemistry have been conducted in Bilate area of the Abaya geothermal prospect.

2.2.2 Surface exploration by private sector

Multiple private sector companies have been involved in surface explorations in their respective concession areas. Accordingly, detailed surface explorations and conceptual modelling have been completed in various prospects including, Dofan, Fentale, Tulu Moye, Corbetti, Wendogenet and Abaya (Figure 1).

2.2.3 Exploration drilling

Exploration drilling has been conducted from the early to mid-1980s at Aluto Langano, in the southern part of the Rift. Eight exploratory wells were drilled with four of these proving productive, with an average electrical output of about 2 MW/well. The other-better explored area including by drilling, is the Tendaho geothermal prospect in northern Afar. Between 1993 and 1998, three deep (about 2,100 m) and three shallow exploratory wells (about 500 m) were drilled in Tendaho 1 area and yielded a temperature of over 250ºC. The Italian and Ethiopian governments jointly financed the drilling operation in the geothermal field. A preliminary production test has indicated that the discovered shallow reservoir at Tendaho 1 alone could generate about 25 MWe. The volumetric estimate of the total Tendaho prospect potential, however, is in the order of several hundred MWs.

2.2.4 Appraisal drilling

The Aluto Langano prospect is the only prospect where appraisal drilling has been conducted or is being conducted. The drilling of two appraisal wells for reservoir modelling and subsequent selection of production wells was carried out in 2013 and 2014 at Aluto 1. These wells, LA-9D and LA-10D, have been directionally drilled to depths of 1920 m and 1951 m respectively. Both wells are productive with bottom hole temperatures of over 300ºC. Testing and reservoir engineering have indicated that the two wells together may sustain about 5 MW of electricity. Reservoir simulation studies have also been conducted using data from the newly drilled two wells at Aluto, including data from previous wells. The result shows that a sustained 35 MW electcity could be generated at Aluto 1.

2.2.5 Geothermal utilization

Geothermal utilization for electrical power generation at Aluto Langano prospect started in 1988 by installing a 7.3 MWe net capacity binary pilot plant. The plant is currently under maintenance and does not produce power.

Direct utilization of the low to medium enthalpy geothermal resources has been so far limited to bathing in spas and swimming pools.

2.2.6 Geothermal master plan study

A geothermal master plan study has been completed recently with JICA technical assistance. The project has conducted geoscientific, social and economic surveys of 22 prospects for potential estimation and to prioritize them. The results of the study have shown an electrical potential of over 10,000 MW. Ranking of the prospects for development has also been made on the bases of geothermal knowledge, potential, project economics, and site-specific factors (GSE and JICA, 2015).

2.3 Current geothermal exploration and development activities

Currently deep geothermal drilling activities are being carried out at Aluto Langano and Tulu Moye prospects by the public and the private sector respectively. A well head turbine is also being installed at Aluto Langano prospect. Using climate technology center and network (CTCN) funds assessments on the most suitable direct use applications in Ethiopia have been carried out.

2.3.1 Current production/exploration drilling and testing at Aluto Langano

The present project in phase 1 foresees the drilling and testing of 6 full diameter production wells at Aluto 1 and 2 exploratory wells at Aluto 2 (Figure 2). Depending on the results of phase 1 drilling, the drilling of additional four wells has also also been planned. The drilling project is being financed by the World Bank under the framework of the Geothermal Sector Development Program (GSDP). The project is being implemented by EEP, with the role of owner and using its newly purchased two deep drilling rigs operating in parallel.

From the end of May 2021 to July 2022 five directional production wells have been completed in Aluto 1 and the drilling of one exploratory well is under progress in Aluto 2. The drilled wells salient data is summarized in Table 2. Until October 2022, discharge tests have been conducted in five of the completed wells. The results have indicated that the drilled wells have a power output of 21.5 MW in total.

TABLE 2: Salient data on recently drilled wells at Aluto Langano prospect

Well name	**Measured depth**	**True vertical depth**	**Kick-off point**	**Horizontal departure**	**Drift angle**	**Azimuth**	**Drilling time**
	(m)	**(m)**	**(m)**	**(m)**	**(°)**	**(°)**	**(days)**
LA -11D-1	3000	2747.14	657	977	26.0	122	121
LA -12D-2	2700	2500	615	857	26.8	173	100
LA -12D-3	2750	2570	589	808	14.6	125	70
LA -13D-1	2875	2513.6	664	1099	37.0	113	78
LA -13D-2	2961	2672.4	610.4	1091	31.1	130	96
BB-1D-1							Current[1]

1) Under drilling and reached 1261 m.

2.3.2 Well head turbine at Aluto Langano

Following the drilling of two appraisal wells at Aluto Langano in 2013/2014 with JICA / World Bank financing and subsequent testing of the wells, the Japanese government has decided to support the installation of a 5 MW well-head turbine using the steam from the two productive wells (LA9 and LA10). Accordingly, the construction housing of the turbine and surface facilities has been completed and installation of the turbine is in progress.

2.3.3 Exploration drilling at Tulu Moye prospect

A private company called Tulu Moye Geothermal has been conducting surface exploration at Tulu Moye geothermal prospect for the last few years with conceptual modelling of the geothermal system to target test exploratory wells. Following the site selection, 4 deep wells have so far been drilled in the area and testing and resource assessment in these wells are currently ongoing.

2.3.4 Direct use studies

With the assistance of the Climate Technology Center and Network (CTCN) studies on direct use have been conducted to identify the most suitable direct-use applications and technologies in low to medium temperature geothermal systems of the country. So far in three areas (Doubti, Aluto Langano and Abaya), potential direct use applications, such as fruit and vegetable drying, aquaculture and fish drying, greenhouse heating, milk pasteurization and balneotherapy have been identified and the technical and economic viabilities of these applications are under assessment in each selected area (CTCN, 2021).

3. Geothermal development plan

According to a recent Ethiopian power system expansion plan study, generation planning has been established for the period up to 2045. It is based on the demand forecast which has indicated both annual energy and peak demand to increase by over three times the 2020 level by 2030 and over eight times the 2020 level by 2045.

Ethiopia is a country with high hydropower potential and aims to be a powerhouse of Africa, exporting electricity to its neighbors. Approximately 95% of generated energy in Ethiopia is in the form of hydropower; however, this makes the system vulnerable to low hydrological conditions, sometimes leading to load shedding. Therefore, the country is keen to increase resilience to drought and therefore wishes to reduce its dependence on hydropower and is aiming for less than or equal to 75% hydro generation by 2030.

Accordingly geothermal being base load and one of the indigenous renewable resources of the country is assigned the development of 980 MW by 2030 in the energy mix. This geothermal development is expected to be achieved by developing already committed projects and candidate projects in various phases as indicated in Table 3 (USAID, 2021).

TABLE 3: Planned production of geothermal electricity in Ethiopia by 2030

Name	**Status**	**Ownership**	**N° units**	$P_{inst.}$ **(MW)**	**Expected commissioning**
Aluto Langano I (rehabilitation)	Committed	EEP	2	9.5	2023
Aluto Langano II	Committed	EEP	2	70	2026
Corbetti I	Committed	IPP	1	50	2024
Corbetti II	Committed	IPP	2	100	2026
Tulu Moye I	Committed	IPP	1	50	2023
Tulu Moye II	Committed	IPP	2	100	2025
Total committed capacity				**380**	
Shashemene Geothermal	Candidate	IPP	2	150	2026
Dugna Fango Geothermal	Candidate	IPP	2	100	2027
Tendaho-Alalobad Geothermal	Candidate	IPP	2	100	2027
Boku Geothermal	Candidate	IPP	2	100	2027
Dofan Geothermal	Candidate	IPP	2	100	2027

Fentale Geothermal	Candidate	IPP	1	50	2027
Shashemene Geothermal	Candidate	IPP	2	150	2027
Total committed and candidate capacity				**980**	

4. CONCLUSIONS

Despite the long history of geothermal exploration in Ethiopia and an estimated potential of over 10,000 MW, so far, only a very small fraction of the total potential has been harnessed. In order to avert possible shortfalls and also due to their added advantage in complementing hydro generation during unfavorable periods of severe droughts, geothermal development in Ethiopia has been given more attention, in recent years.

980 MWe has been planned to be developed from geothermal by 2030. However, planning alone cannot fast track resource development. In addition to planning: (i) the government has to assign a sufficient budget, build enough capacity and set appropriate institutional set-up to remove the risk barriers; (ii) facilitate PPA negotiations with private companies; (iii) establish and implement geothermal laws and regulations; and (iv) create appropriate enabling environments for private sector investment.

Currently: (i) geothermal is integrated into the National Energy Development Master Plan; (ii) participation of international financial institutions, bilateral donors and development agencies to assist geothermal development projects has grown; (iii) the public sector is implementing various geothermal projects, and the private sector is being encouraged to participate in geothermal development projects. Therefore, Ethiopia is expected to connect hundreds of Mega Watts of geothermal power to the grid in the long term.

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